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(54) Optical switching device

(57) An optical switching device comprises a plurality of electrically-controllable birefringence cells 29, 31, for example liquid crystal pi-cells, arranged in series, so that light passes through the cells in sequence. The cells are arranged between two polarising films 25,27, and each cell comprises a liquid crystal film 1,3 contained between a pair of parallel glass plates 5,7,9 separated by spacers 11. Electrical leads 15,17 are connected to transparent conductive coatings 13 on the surface of plates 5,7,9 adjacent to the films 1,3. Synchronised electric fields are applied across the cells to change the phase retardation of the light transmitted through the device from a first value to a second value. Each cell has a time-dependent birefringence after cessation of the fields such that the time taken for the phase retardation produced by the device to change back from the second value to the first value is less than the time taken for each cell to relax back to its equilibrium state. The cells preferably include a single-frequency or a two-frequency nematic liquid crystal material.

Fig. 1.

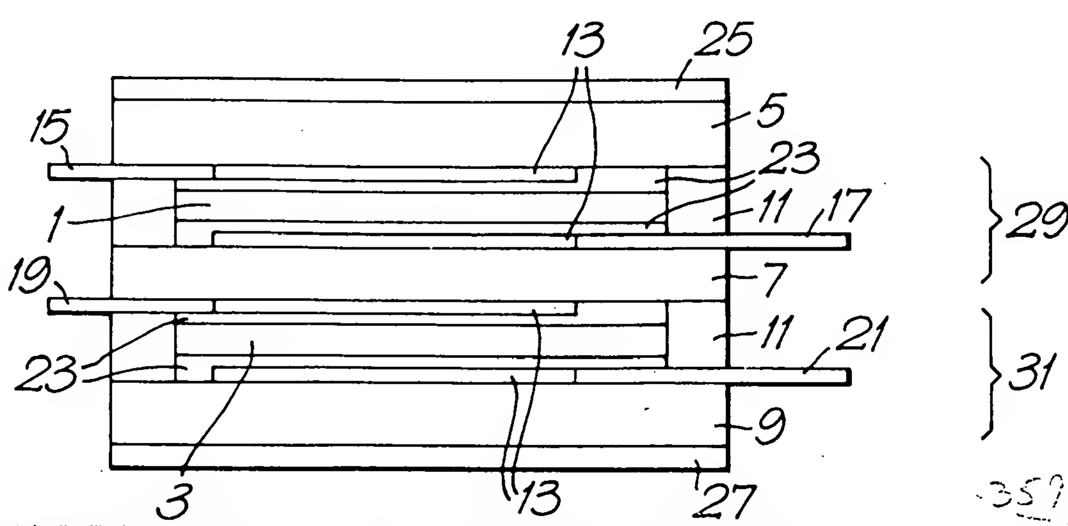

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Fig.1.

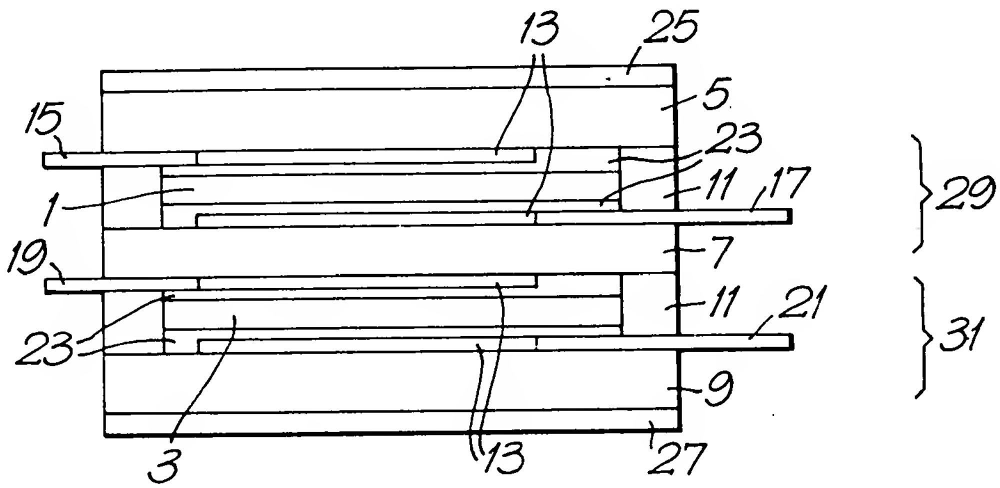


Fig.2.

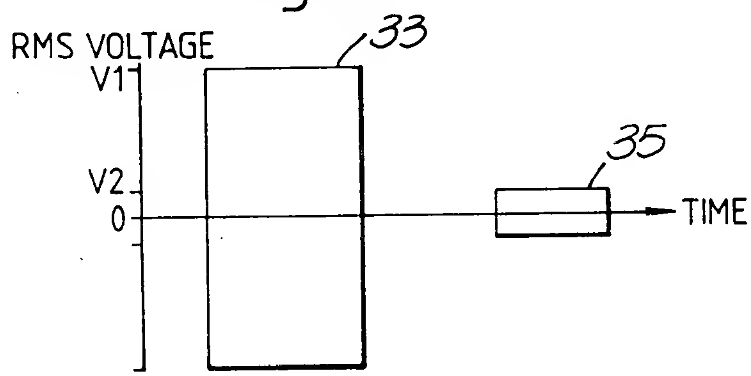
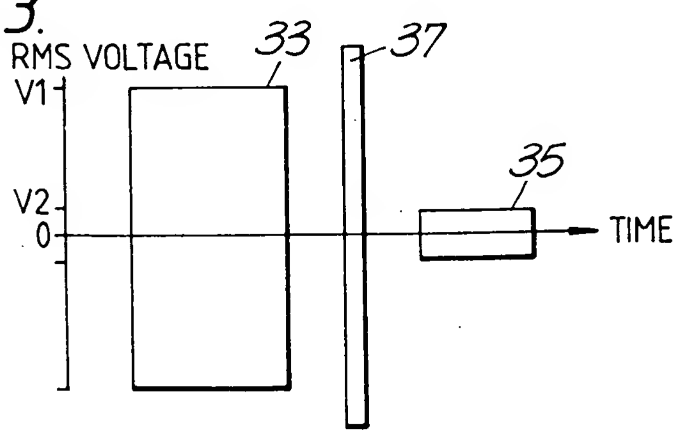


Fig.3.



SPECIFICATION

Optical switching device

This invention relates to optical switching devices. In particular the invention relates to electrically operated optical switching devices which are capable of very fast switching rates. Such devices are required, for example in field-sequential colour displays, as described in U.K. Patent Number 1,491,471.

In an article in Mol. Cryst. Liq. Cryst. volume 113, pages 329–330 published in 1984 there is described an optical switching device for use in a field-sequential colour display. The device incorporates so-called liquid crystal "pi-cell". This comprises a nematic liquid crystal contained between two parallel plates, the surfaces of the plates adjacent to the liquid crystal being treated such that the directors of the liquid crystal adjacent to the surface lie at the same angle to the surfaces, the directors adjacent to the two surfaces being tilted in opposite senses, the direction of the directors varying homogeneously across the cell in the direction normal to the plates. By applying repetitive pulses of an AC voltage across the cell, the directors remote from the confining surfaces of the plates may be caused to rotate to a position in which they are normal to the planes of the plates. Under this condition the extra-ordinary ray generated by linearly polarised normally incident light of a particular wavelength determined by the spacing of the plates transmitted through the cell during a voltage burst experiences a half-wave phase change compared to the extraordinary ray transmitted through the cell during the interval when no AC voltage is applied across the cell, the directors relaxing back to a less tilted alignment on cessation of the AC voltage. Thus by use of appropriate polarisers the required switching operation on the light transmitted by the cell may be achieved.

Such a device, whilst relatively fast, has generally a frame frequency of less than 100Hz, with turn-off times greater than 1 msec. For some applications faster frame rates and turn-off times are desired.

It is an object of the present invention to provide an optical switching device capable of a faster switching rate than has hitherto been possible.

According to the present invention an optical switching device includes a plurality of electrically controllable birefringence cells arranged such that incident light passes through the cells in sequence, and means for applying synchronised electric fields across each cell so as to change the phase retardation of the light transmitted through the device from a first value to a second value, each cell having a time dependent birefringence after cessation of said fields such that the time taken for the phase retardation produced by the device to change back from the second value to the first value is less than the time taken for each cell to relax back to its equilibrium state.

Each electrically controllable birefringence cell is suitably a liquid crystal pi-cell.

One optical switching device in accordance with the invention will now be described, by way of example only, with reference to the accompanying drawings in which:

Figure 1 is a schematic side view of the device;

Figure 2 illustrates the voltages pulse sequence applied to the device shown in Fig. 1; and

Figure 3 illustrates an alternative voltage pulse sequence applied to the device shown in Fig. 1.

Referring firstly to Fig. 1 the device includes two films 1, 3 of the nematic liquid crystal 1132 produced by Merck, each film having a nominal thickness of 8.5μm. The films are each contained between pairs of parallel glass plates 5 and 7, 7 and 9 separated by spacers 11. On the surfaces of the plates, 5, 7, 9 adjacent to the films 1, 3 there are provided transparent conductive coatings 13 in a pattern forming the active areas of the device, electrical leads 15, 17, 19, 21 being provided to the coatings 13. The surfaces of the coatings 13 adjacent to the films 1,3 carry barrier layers (not shown) as is usual in liquid crystal devices together with alignment layers 23 in the form of obliquely evaporated silicon monoxide layers obliquely evaporated at an angle of 5° to the plates 5,7,9.

The device is constructed such that the directors of the liquid crystal films 1,3 adjacent to the alignment layers 23 lie at the same angle to the surfaces of the plates 5,7,9, the directors at opposite sides of each film 1, 3 being tilted in opposite senses, the alignment directions of the films 1, 3 being parallel or antiparallel to each other.

at the outer surfaces of the plates 5,9 there are provided respective polarising films 25,27 the first polarising film 25 being arranged with its transmission axis set at 45° to the alignment directions of the liquid crystal films 1,3, the second polarising film 27 being arranged with its transmission axis either crossed or parallel to the first polarising film 25.

Thus the device comprises two liquid crystal pi-cells 29,31 arranged in series between the polarising films 25,27.

Referring now also to Fig. 2, in use of the device an external voltage source (not shown) is used to apply bursts of 1kH, square wave signals across each of the films 1,3 via the leads 15, 17, 19, 21. The cells 29, 31 are driven in synchronism with pulse envelopes as indicated by 33 in Fig. 2 amplitude V_1, this causing the cells 29, 31 to switch to an "ON" state in which the greatest fraction of the directors of the liquid crystal films 1, 3

remote from the alignment layers 23 are aligned in a direction normal to the planes of the plates 5, 7, 9 and the relative phase retardation between ordinary and extraordinary rays of light transmitted through the active portion of the device is a minimum.

On cessation of the voltage V_1 applied across the cells 29, 31 a fraction of the directors will relax back to a less tilted alignment and the relative phase retardation between ordinary and extraordinary rays will increase until it reaches the value required for the "OFF" state of the device. At this point a second pulse envelope 35 of 1kH, square wave signals of amplitude V_2 is applied to stabilise the phase retardation at this value. The voltage V_1 will typically be an RMS value of 20 volts whilst an RMS value of between 0 and 5 volts is typically adequate for V_2. The combination of the polarising films 25,27 will of course cause the device to perform the requiring switching function.

It is found that the turn-off time of the above device is decreased by a factor of more than 2 over an equivalent device incorporating a single liquid crystal pi-cell, thus correspondingly increasing the switching speed and thus the frame frequency of the device.

In one specific device in accordance with the invention constructed by the inventors two liquid crystal pi-cells each of which individually had turn-off times of 4 msecs had a turn-off time of 1 msec when combined in series as described above.

This result in in contradistinction to an equivalent optical switching device incorporating a series arrangement of two twisted nematic liquid crystal cells as described for example in U.K. Patent No. GB 2042202B. In such a device no gain in turn-off speed would be obtained by using two twisted nematic cells instead of one as the turn-off time in such a device would be determined by the time to regain guiding of polarised light by the slower of the two cells. Furthermore it is essential to place an additional polarising film between the two cells, thus further increasing the attenuation and obliging the plate 7 to be a laminate. It is also in contradistinctionn to an equivalent optical switching device incorporating a series arrangement of two chiral smectic liquid crystal cells as described for example by an article in Applied Physics Letters, volume 36, pages 899–901 published in 1980. In such cells the optic axis is rotated in the plane of the liquid crystal film, and thus the time taken to complete a desired rotation of the optic axis is determined by the slower of the two cells.

The advantageous effect in the series arrangment of the two pi-cells can be explained by the fact that the effective birefringence of the device changes during switching, but the direction of the optic axis within each cell 29, 31 does not. Thus considering the turn-off time the change in phase difference δ_1, between the transmitted ordinary and extraordinary rays of light as a function of time may be approximated for a single pi-cell by the expression:

$$\delta_1(t) = \delta_0(1 - \delta e^{-t/\tau})$$

where τ is a time constant, and where $0 << \alpha < 1$ is a function of the applied "ON" voltage, tending to unity as the ON voltage tends to infinity, and δ_0 is the "OFF" state phase retardation of the cell when no voltage is applied across the cell.

An equivalent expression for the phase difference δ_2 for the double pi-cell shown in Fig. 1 may be given by:

$$\delta_2(t) = 2\delta_0(1 - \alpha e^{-t/\tau})$$

The ratio of the times t_1 and t_2 required to attain the same phase difference δ on single and double cell devices respectively is thus given by

$$\frac{t_2}{t_1} = \frac{\ln\left[\frac{1}{\alpha}\left(1 - \frac{\delta}{2\delta_0}\right)\right]}{\ln\left[\frac{1}{\alpha}\left(1 - \frac{\delta}{\delta_0}\right)\right]}$$

The underlying table shows a calculated range of the ratios of turn-off times $t_2 t_1$ for a single pi-cell and an equivalent device in accordance with the invention incorporating two pi-cells for different values of the change in relative retardation δ/δ_o.

t_2/t_1	a=0.95	α=1.0
δ/δ_0=0.1	---	0.487
0.2	0.315	0.472
0.3	0.364	0.456
0.4	0.374	0.437
0.5	0.368	0.415
0.6	0.353	0.389

It is also found that whilst the voltage V_1 used in the first pulse envelope will be the same as for a single cell device the voltage V_2 required to stabilise the device in the OFF state will be greater than for a single pi-cell device as the individual cells 29,31 are being stabilised at approximately one half the total OFF state relative retardation of the whole device.

For example in the specific device constructed by the inventors described above the voltages used were V_1=20 volts and V_2=2.5 volts for a single cell, V_2=4.5 volts for the two cells in the series.

It will be appreciated that there will be variation in the way in which the device is driven. The voltages V_1 and V_2 may be different for the two cells 29, 31 to correct for any variation between the cells such as difference in thickness between the films 1,3.

Turning now to Fig. 3, in a variation of the

above device, if the cells 29, 31 are filled with a "two frequency" nematic liquid crystal, the turn-off time may be further decreased by insertion of a short, high frequency voltage burst 37 between the pulses 33, 35 using the "two frequency" switching technique as described by Bucher et al, in Applied Physics Letters, volume 24, pages 186–8 published in 1974.

It will be appreciated that many variations in the liquid crystal pi-cells described hereinbefore will be apparent to those skilled in the art. In particular it is clear that the plate 7 may be replaced by two plates cemented together to make an optionally homogeneous whole.

It will also be appreciated that whilst the optical switching device described above by way of example incorporates liquid crystal pi-cells, devices in accordance with the invention may incorporate alternative electrically controllable birefringence cells displaying the required characteristics. One example of such an alternative birefringence cell is a Kerr cell.

It will also be appreciated that whilst the optical switching device described herebefore by way of example incorporates two birefringence cells arranged in series, a further decrease in turn-off time may be obtained by using three or more cells in series, although a practical upper limit on the number of cells incorporated will be imposed by cost, complexity and light attenuation. It was found for a series combination of three liquid crystal pi-cells each individually having a turn-off time of 4msecs, that a turn-off time of 0.4msecs was obtained.

It will be appreciated that a device in accordance with the invention will have many applications other than in the field-sequential colour display mentioned above. These include monochrome TV rasters in which colour overlays are written cursively during the frame flyback time, flood-gun dedicated-format displays as described in U.K. Patent GB 2131225B, and active contrast-enhancement filters as described in U.S. Patent S.N. 4231068. It will also be appreciated that advantages resulting from use of a device in accordance with the invention in field-sequential colour displays include improved freedom from flicker in both raster and cursively written two and three primary colour displays and avoidance of the need for a split screen such as is described in U.K. Patent GB 2,042202B. The display device associated with the colour switching device may be any emissive display device in which the spectral and temporal characteristics of the emission are suitable for the application.

It will be further appreciated that devices in accordance with the invention will have application in field-sequential stereoscopic displays, in which two fields carrying left-eye and right-eye views are alternately presented, each of the fields possibly being a full-colour image.

CLAIMS

1. An optical switching device including a plurality of electrically controllable birefringence cells arranged such that incident light passes through the cells in sequence, and means for applying synchronised electric fields across each cell so as to change the phase retardation of the light transmitted through the device from a first value to a second value, each cell having a time dependent birefringence after cessation of said fields such that the time taken for the phase retardation produced by the device to change back from the second value to the first value is less than the time taken for each cell to relax back to its equilibrium state.

2. A device according to Claim 1 in which each electrically controllable birefringence cell is a liquid crystal pi-cell.

3. An optical switching device substantially as hereinbefore described with reference to the accompanying drawings.

CLAIMS

Amendments to the claims have been filed, and have the following effect:–

Claims 1–3 above have been deleted.

New claims have been filed as follows:–

1. An optical switching device, including a plurality of electrically-controllable birefringence cells arranged such that incident light passes through the cells in sequence, and means for applying synchronised electric field across the cells so as to change the phase retardation of the light transmitted through the device from a first value to a second value, each cell having a time-dependent birefringence after cessation of said fields such that the time taken for the phase retardation produced by the device to change back from the second value to the first value is less than the time taken for each cell to relax back to its equilibrium state.

2. A device according to Claim 1, in which each electrically-controllable birefringence cell is a liquid crystal pi-cell.

3. A device according to Claim 2, in which each cell includes a single-frequency nematic liquid crystal material.

4. A device according to Claim 2, in which each cell includes a two-frequency nematic liquid crystal material.

5. A device according to Claim 2, Claim 3 or Claim 4, in which the liquid crytal material is contained between parallel light-transmitting plates, and in which there is a single one of said plates between adjacent cells, which plate is common to said adjacent cells.

6. An optical switching device substantially as hereinbefore described with reference to the accompanying drawings.

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